Remotely Sensed Tropical Cyclone Structure/Intensity Changes

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LONG-TERM GOAL

Our long-term goal is to understand the structure and evolution of tropical cyclones, such that Navy estimates of location and intensity are highly accurate and successfully impact medium/short-term decision-making.

OBJECTIVES

Our objective is to accurately map the structure of tropical cyclones throughout their lifetime and better understand the temporal changes under all-weather conditions. Accurate knowledge of the storm's structure will enable enhanced knowledge of storm location and intensity in near real-time.

APPROACH

Passive microwave digital data will be utilized to mitigate the natural limitations inherent with both visible and Infrared (IR) imagery when applied to the tropical cyclone (TC) monitoring mission. Upper-level clouds often obscure mid-/low-level cloud structure that is crucial in accurately accessing the current location and intensities of TCs around the world. Passive microwave frequencies can "see" below upper-level cirrus on a routine basis and permit the user to map the rainbands, eyewalls and eye structure not feasible with vis/IR imagery.

There are currently two satellite platforms that carry passive microwave sensors in polar orbit; a) the Defense Meteorological Satellite Program (DMSP) and its Special Sensor Microwave/Imager (SSM/I), and b) the Tropical Rainfall Measuring Mission's (TRMM) Microwave Imager (TMI). The 85, 37, 22, and 19 GHz frequencies on each sensor measure brightness temperatures that are directly impacted by the scattering due to medium-large ice particles aloft and absorption due to rain. These particles are well correlated with intense convection associated with TC rainbands, eyewalls and mesocale convective systems. Thus, the scattering produces dramatically lowered brightness temperatures that effectively highlight the TC structure desired and produces images similar to that of a land-borne radar. Jeff Hawkins, Joe Turk, and Tom Lee are the contributors on use of the imagery, while Paul Tag, Richard Bankert and Juanita Sandidge are investigating the automated intensity analysis.

NRL is incorporating the TRMM precipitation radar (PR) with the passive microwave sensors to leverage the greatly enhanced vertical and horizontal resolutions in this unique data set. The TRMM PR enables us to compare coarser resolution rainrates from the SSM/I and TMI and map the 3-D rain structure unlike any previous satellite remote sensor. The PR is thus valuable in providing a

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benchmark for other sensors that have much larger swaths, but suffer from a variety of limitations. Joe Turk (NRL) is working with colleagues at NASA/GSFC (Goddard Space Flight Center).

Project team:
Jeffrey D. Hawkins — team leader, satellite meteorologist
Joe Turk — satellite meteorologist
Tom Lee - satellite meteorologist
Paul Tag — computer vision, expert systems, AI
Richard Bankert — computer vision, expert systems, AI
Juanita Sandidge — neural networks
Arunas P. Kuciauskas—satellite meteorologist

WORK COMPLETED

Over 2,700 SSM/I passive microwave images coincident with tropical cyclones have been processed. SSM/I data from 1987-1999 onboard DMSP satellites F-8, F-9, F-10, F-11, F-13, and F-14 have been processed with software designed to glean full capabilities from the 85 GHz images. Special processing has enabled 1-2 km resolution 85 GHz images to be directly compared with coincident OLS IR and geostationary vis/IR data sets. Data set includes systems from depression status (30 kt) to Super Typhoon or Category 5 (150 kt) in the Atlantic, Pacific and Indian Ocean basins. Computer vision and neural network methods have been run on this enhanced data set.

TMI digital data is received in near real-time from NASA-GSFC and processed for all active TCs around the globe. TMI data has been processed and collocated with coincident geostationary vis/IR data and posted on the NRL-MRY tropical cyclone web page: http://www.nrlmry.navy.mil/sat-bin/tc_home . Comparisons with SSM/I data at multiple frequencies have revealed capabilities of TMI not feasible with SSM/I data sets. TRMM PR data has been collected and is being compared with rainrates derived from coarser SSM/I and SSM/I-IR techniques around tropical cyclones.

Advanced Microwave Sounding Unit (AMSU-A) data has been collected and processed for the 1999 TC season and is now undergoing extensive research. Excellent data sets for Dennis, Floyd, Gert, Irene and Jose that include multiple aircraft monitoring will provide the ground truth needed for this technique to evolve to the next level. Additional data from the Pacific basins has been collected, though the Western Pacific season has not been normal. Chris Velden from the Cooperative Institute for Meteorological Satellite Studies (CIMSS- University of Wisconsin) heads this task.

RESULTS

Computer vision and neural network algorithms have been applied to an enlarged passive microwave TC data set. Results when applied to individual storms throughout their lifetime are very encouraging and have basically reached the likely limits of the best-track intensity database (~ 15 kt). These accuracy levels are comparable to long-term Dvorak values, allowing us to move onto the next phase of testing. This effort has been transitioned to 6.4 (0603207N Spawar-185) and implies that the pattern correlations in passive microwave storm images are well in sync with intensity.

TMI data has supplemented SSM/I data in two ways: a) providing TC views at non-SSM/I times, and b) permitting much higher spatial resolution views at lower frequency channels. The TRMM orbit compliments the SSM/I constellation and increases the temporal updates. More frequent imagery has allowed better definition of TC concentric eyewall cycles, which are turning out to be very important short-term intensity indicators. The ability to use 37 GHz at high resolution has shown promise in mapping TC structure not feasible with 85 GHz. Penetration further into the TC structure with 37 GHz shows obvious benefits, such as depicting exposed nighttime low-level circulation centers (LLCC) that are difficult to see in IR imagery. TMI data is now routinely posted on web page noted above and data is also sent to JTWC in digital form. This effort is being transitioned to FNMOC per request from JTWC.

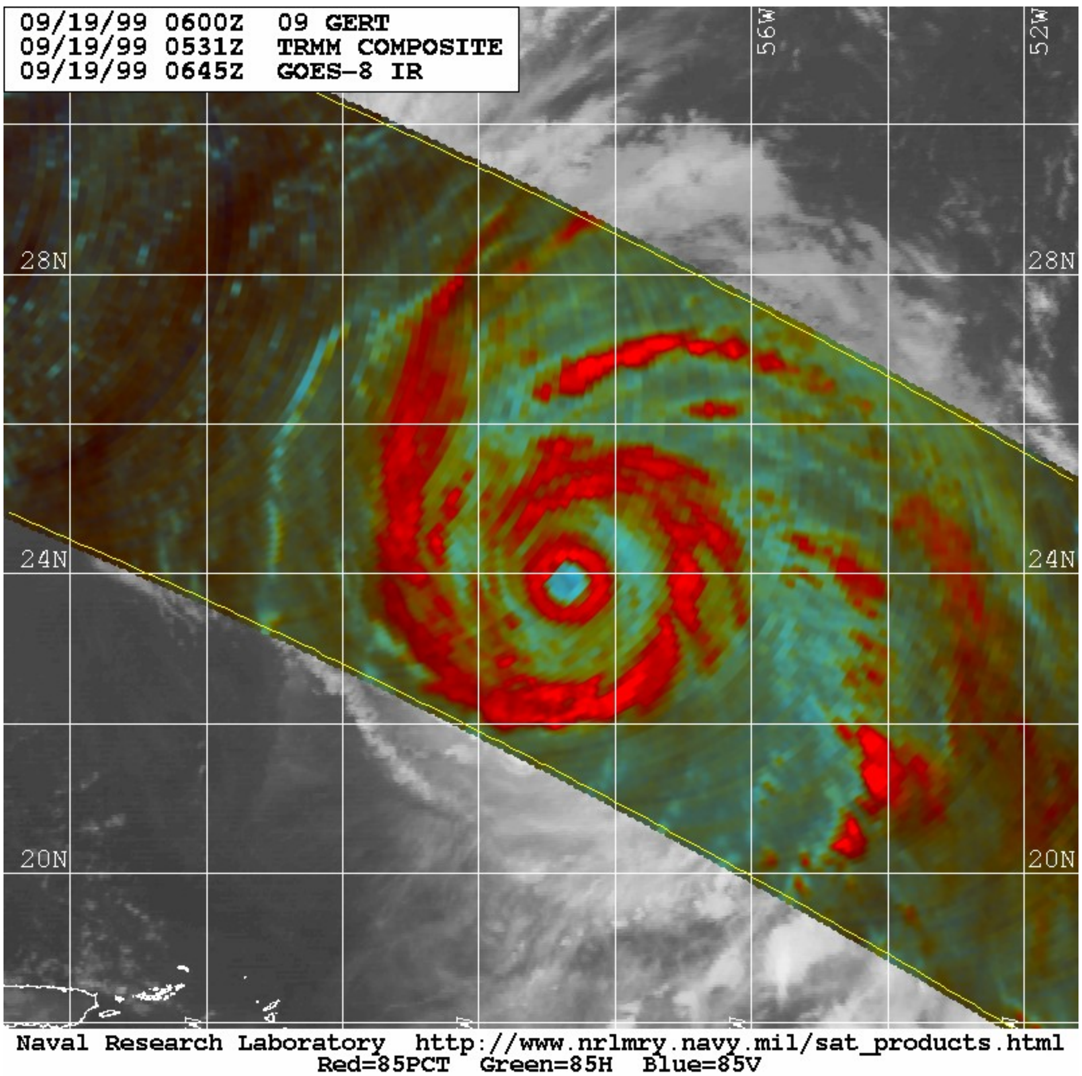

Figure 1: TMI multi-channel imagery for Hurricane Gert on Sept. 19, 1999 at 0531 GMT. Swath represents a combination of 85 GHz vertical and horizontal polarization SSM/I data, while data outside swath is coincident GOES-9 IR imagery. Red values in 85 GHz imagery represent large scattering due to ice particles above inner eyewall (note clear center) and nicely map the formation of strong secondary eyewall. Storm began eyewall replacement cycle at this time.

Preliminary results from AMSU-A matchups with TCs indicate significant improvement in mapping the upper-level warm core temperature anomaly when compared with previous Microwave Sounding Unit (MSU) data. Limb and channel bias corrections are ongoing while creating database with corresponding aircraft-derived intensity values. Once validation has occurred, team envisions creating a multi-pronged effort that uses Objective Dvorak, SSM/I and AMSU intensities to glean the best satellite intensity estimate possible.

IMPACT/APPLICATIONS

Intelligent use of passive microwave data over tropical cyclones can greatly increase our knowledge of TC structure and thus location and intensity. Tropical cyclone warnings are thus directly affected and they in turn have a direct impact on the course of action taken by Navy/Marine assets in a storm's path. Note that one Norfolk fleet sortie costs from $3-5M, thus accurate predictions are crucial and must begin with precise initial conditions. Accurate tropical cyclone warnings/forecasts by JTWC and the regional centers and facilities can be strongly tied to the success of our overall TC satellite reconnaissance capability.

TRANSITIONS

Results from the two automated passive microwave intensity techniques have been transitioned to 6.4 (PE 0603207N Spawar-185). Near real-time SSM/I and TMI digital data is now sent to JTWC from NRL-MRY as part of the 6.4 demo effort. This capability to use both data sets has proven critical to JTWC operations and thus the current request to transition this functionality to FNMOC. JTWC now views 37 GHz imagery as result of this 6.2 work to transition this functionality to FNMOC.

TRMM precipitation radar values have assisted in combined passive microwave-IR rainrate assimilation techniques. Assimilation of satellite-derived rainrates has been transitioned to 6.4 after multiple positive tests with NOGAPS physical initialization were accomplished by Greg Rohaly and Joe Turk.

RELATED PROJECTS

This 6.2 effort has a collaborative 6.4 work unit entitled "Tropical Cyclone Intensity and Structure Via Multi-Sensor Combinations" funded by SPAWAR PMW-185, PE 0603207N. The vertical integration of these 6.2/6.4 efforts has been instrumental in obtaining rapid progress via shared data sets, resources, expertise and knowledge of what is needed by the operational end user. This project is in constant contact with airborne research work carried out by NOAA's Hurricane Research Division and the TRMM team efforts at NASA/GSFC, especially the CAMEX field program.

PUBLICATIONS

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